

This listing of claims will replace all prior versions,
and listings, of claims in the application:

1 Claim 1 (currently amended): An apparatus for generating
2 at least one hybrid arc/microwave plasma discharge, the
3 apparatus comprising:
4 a) a cavity adapted to support at least one of a TE
5 mode and a TM mode at a microwave frequency; ~~and~~
6 b) ~~a~~ an arc torch module, coupled with the cavity,
7 for generating seed plasma within the cavity; and
8 c) a microwave source, coupled with the cavity, for
9 generating microwaves at the microwave frequency, and
10 for introducing the generated microwaves into the
11 cavity,
12 wherein the arc torch module is capable of
13 generating a plasma torch which exits the cavity in
14 the absence of microwave energy, said generated plasma
15 torch having a first energy level.
16

1 Claim 2 (original): The apparatus of claim 1, wherein the
2 cavity is a tapered cavity.

Claim 3 (cancelled)

1 Claim 4 (currently amended): The apparatus of claim 1,
2 ~~wherein the torch module is an arc torch module, and~~
3 wherein the seed plasma generated by the arc torch module
4 discharge triggers microwave discharge in the cavity
5 thereby generating additional plasma.

1 Claim 5 (original): The apparatus of claim 4 wherein an
2 exit opening is defined in the cavity at a location
3 opposite the arc torch module, wherein plasma is generated
4 by a combination of an arc discharge and microwave
5 discharge, and wherein the generated plasma exits the
6 cavity through the exit opening as the hybrid arc/microwave
7 discharge.

1 Claim 6 (currently amended): An apparatus for generating
2 at least one hybrid arc/microwave plasma discharge, the
3 apparatus comprising:
4 a) a cavity adapted to support at least one of a TE
5 mode and a TM mode at a microwave frequency ~~The~~
6 ~~apparatus of claim 1,~~ wherein, said cavity includes a
7 first wall and a second wall opposing the first wall,
8 wherein the torch module is fitted into the first wall
9 of the cavity, and wherein an exit opening is defined
10 in the second wall of the cavity at a location opposed
11 to the location of the torch module; and
12 b) a torch module, coupled with the cavity, for
13 generating seed plasma within the cavity.

1 Claim 7 (original): The apparatus of claim 1, wherein said
2 cavity has a narrow section, a wide section, and a tapered
3 section arranged between the narrow and wide sections.

1 Claim 8 (currently amended): An apparatus for generating
2 at least one hybrid arc/microwave plasma discharge, the
3 apparatus comprising:
4 a) a cavity adapted to support at least one of a TE
5 mode and a TM mode at a microwave frequency,

6 wherein said cavity has a narrow section, a wide
7 section, and a tapered section arranged between the
8 narrow and wide sections and ~~The apparatus of claim 7~~
9 wherein both the narrow section and the wide section
10 have rectangular cross sections; and
11 b) a torch module, coupled with the cavity, for
12 generating seed plasma within the cavity.

1 Claim 9 (original): The apparatus of claim 8, wherein the
2 cavity is dimensioned to support a TE_{10n} mode at the
3 microwave source frequency, wherein n is an integer that is
4 at least 3.

1 Claim 10 (original): The apparatus of claim 6, wherein
2 said cavity includes
3 - endwalls substantially orthogonal to the first and
4 second wall, and
5 - additional walls arranged between the endwalls and
6 including the first and second walls,
7 wherein the hybrid arc/microwave plasma discharge
8 exits the cavity from the exit opening of the second wall.

1 Claim 11 (withdrawn): The apparatus of claim 1, further
2 comprising at least one additional torch module coupled
3 with the cavity, wherein the seed plasma generated by the
4 arc discharges of the torch modules is energized by a TE
5 mode electric field rather than by a TM mode, the seed
6 plasma triggering subsequent microwave discharges thereby
7 generating at least two hybrid arc/microwave plasma
8 discharges.

1 Claim 12 (withdrawn): The apparatus of claim 11, wherein,
2 said cavity includes a first wall and a second wall
3 opposing the first wall, wherein the torch modules are
4 fitted into the first wall of the cavity, and wherein exit
5 openings are defined in the second wall of the cavity at a
6 location opposed to the location of the torch modules,
7 wherein said cavity includes endwalls substantially
8 orthogonal to the first and second walls, and wherein the
9 hybrid arc/microwave plasma discharges exit the cavity from
10 the two exit holes of the second wall.

1 Claim 13 (original): The apparatus of claim 10, wherein
2 said cavity has a narrow section, a wide section, and a
3 tapered section arranged between the narrow and wide
4 sections,
5 wherein said cavity includes a narrow section defined
6 by the additional walls, the narrow section having a height
7 of about 5 mm, a first of the additional walls having a
8 first opening defined therein at which the torch module is
9 fixed, a second of the additional walls having a second
10 opening defined therein,
11 wherein the second opening permits the hybrid
12 arc/microwave plasma torch to exit, and
13 wherein the first and second openings are located at
14 one of the electric field maximum locations of the TE_{10n}
15 mode, and the tapered section including two end locations,
16 the end locations of the taper section located at electric
17 field minimum locations of said TE_{10n} mode.

1 Claim 14 (currently amended): An apparatus for generating
2 at least one hybrid arc/microwave plasma discharge, the
3 apparatus comprising:

4 a) a cavity adapted to support at least one of a TE
5 mode and a TM mode at a microwave frequency,
6 wherein said cavity has a narrow section, a wide
7 section, and a tapered section arranged between the
8 narrow and wide sections ~~The apparatus of claim 7, and~~
9 wherein the narrow section has a length of about
10 $m\lambda_z/2$, where λ_z is the wavelength of said TE_{10n} mode
11 in the axial direction of the cavity, and m is an
12 integer determined by the number of torches to be
13 hosted in said cavity; and
14 b) a torch module, coupled with the cavity, for
15 generating seed plasma within the cavity.

1 Claim 15 (currently amended): An apparatus for generating
2 at least one hybrid arc/microwave plasma discharge, the
3 apparatus comprising:

4 a) a cavity adapted to support at least one of a TE
5 mode and a TM mode at a microwave frequency,
6 wherein said cavity has a narrow section, a wide
7 section, and a tapered section arranged between the
8 narrow and wide sections; and
9 b) a torch module, coupled with the cavity, for

10 generating seed plasma within the cavity ~~The apparatus~~
11 ~~of claim 7,~~ wherein said cavity is a low Q cavity with a
12 value less than 30,

13 wherein said torch module generates seeding plasma
14 generating additional plasma without requiring microwave
15 breakdown, and

16 wherein said cavity includes an exit opening to exit
17 the hybrid arc/microwave plasma discharge, said exit
18 opening having a larger diameter than would be possible if

19 said torch module did not generate seeding plasma, said
20 larger diameter exit opening resulting in a increase in the
21 size of the plasma discharge.

1 Claim 16 (original): The apparatus of claim 1, wherein
2 said torch module includes a frame, a central electrode,
3 and a ceramic insulator, the frame including an outer
4 electrode which is electrically connected to the cavity,
5 the ceramic insulator insulating the central electrode from
6 the frame of the module and from the cavity.

1 Claim 17 (original): The apparatus of claim 16, wherein
2 said torch module frame includes openings to couple inlet
3 gas into a gas chamber of said torch module.

1 Claim 18 (original): The apparatus of claim 1, wherein the
2 hybrid arc/microwave plasma discharge forms a column, said
3 column reaching a height of about 6 cm and a diameter of
4 about 2 cm.

Claims 19 and 20 (cancelled)

1 Claim 21 (currently amended): An apparatus for generating
2 at least one hybrid arc/microwave plasma discharge, the
3 apparatus comprising:

- 4 a) a cavity adapted to support at least one of a TE
5 mode and a TM mode at a microwave frequency;
6 b) a torch module, coupled with the cavity, for
7 generating seed plasma within the cavity;
8 c) a microwave source, coupled with the cavity, for
9 generating microwaves at the microwave frequency, and

10 for introducing the generated microwaves into the
11 cavity;
12 d) a first power supply module to power the microwave
13 source; and
14 e) a second power supply module to power the torch
15 module,
16 wherein the first and second power supply modules
17 share a common transformer ~~The apparatus of claim 20, and~~
18 wherein primary input power is selected from at
19 least one of a 60Hz, 50Hz, and 400Hz AC primary power
20 source, wherein the time average power of approximately
21 700W is supplied by said first power supply module, and
22 wherein hybrid arc/microwave discharge has a cycle energy
23 of approximately 12 J/cycle

1 Claim 22 (currently amended): An apparatus for generating
2 at least one hybrid arc/microwave plasma discharge, the
3 apparatus comprising:
4 a) a cavity adapted to support at least one of a TE
5 mode and a TM mode at a microwave frequency;
6 b) a torch module, coupled with the cavity, for
7 generating seed plasma within the cavity;
8 c) a microwave source, coupled with the cavity, for
9 generating microwaves at the microwave frequency, and
10 for introducing the generated microwaves into the
11 cavity;
12 d) a first power supply module to power the microwave
13 source; and
14 e) a second power supply module to power the torch
15 module,

16 wherein the first and second power supply modules
17 share a common transformer ~~The apparatus of claim 20, and~~
18 wherein, the first power supply module includes a
19 coupling capacitor of approximately 1 micro-Farad, wherein
20 the second power supply includes a coupling capacitor of 1
21 micro-Farad and a limiting resistor of approximately 750
22 ohms, and wherein the common transformer has a turns ratio
23 of approximately 1:25.

1 Claim 23 (currently amended): An apparatus for generating
2 at least one hybrid arc/microwave plasma discharge, the
3 apparatus comprising:

4 a) a cavity adapted to support at least one of a TE
5 mode and a TM mode at a microwave frequency ~~The~~
6 ~~apparatus of claim 3,~~ wherein the cavity is
7 dimensioned to support a TE_{10n} mode at the microwave
8 source frequency, where n = 3, wherein the microwave
9 frequency is approximately 2.45 GHz, and wherein the
10 cavity includes a first section, a second section, and
11 a third section, said first section having the
12 dimensions of a S-band WR-284 waveguide of
13 approximately 7.2 cm x 3.4 cm and a length of
14 approximately 8.74 cm, said third section having the
15 dimensions of approximately 7.2 cm x 0.5 cm and a
16 length of approximately 11.65 cm, said second section
17 being a middle section, being tapered, having a width
18 of approximately 7.2 cm, a height ranging from
19 approximately 3.4 cm to approximately 0.5 cm, a length
20 of approximately 11.65 cm and a slope angle of
21 approximately 14 degrees;

22 b) a torch module, coupled with the cavity, for
23 generating seed plasma within the cavity; and

24 c) a microwave source, coupled with the cavity, for
25 generating microwaves at the microwave frequency, and
26 for introducing the generated microwaves into the
27 cavity.

1 Claim 24 (currently amended): An apparatus for supporting
2 generation of at least one hybrid arc/microwave plasma
3 discharge, the apparatus comprising:
4 a) a cavity supporting at least one of a TE mode and
5 a TM mode at a microwave frequency; ~~and~~
6 b) means for coupling at least one arc torch module
7 to said cavity; and
8 c) means for a plasma torch to exit the cavity,
9 wherein said means for coupling at least one arc torch
10 module to said cavity is on a first wall of the cavity,
11 wherein said means for a plasma source to exit the cavity
12 is located on a second wall of the cavity, wherein said
13 first and second walls are different, and wherein said
14 first and second walls are substantially planar.

1 Claim 25 (original): The apparatus of claim 24, wherein
2 the means for coupling at least one torch module include a
3 threaded portion attached to a wall of said cavity.

1 Claim 26 (original): The apparatus of claim 24, wherein
2 the dimensions of the cavity support a TE_{10n} mode at the
3 microwave source frequency, where n is an integer of at
4 least 3.

1 Claim 27 (withdrawn): The apparatus of claim 24, further
2 comprising:

3 c) means for coupling at least one additional torch
4 module to said cavity, wherein said torch plasma is
5 energized by a TE mode electric field rather than by a
6 TM mode, and wherein at least two hybrid arc/microwave
7 plasma discharges are generated.

1 Claim 28 (currently amended): An apparatus for supporting
2 generation of at least one hybrid arc/microwave plasma
3 discharge, the apparatus comprising:

4 a) a cavity supporting at least one of a TE mode and
5 a TM mode at a microwave frequency; and

6 b) means for coupling at least one torch module to
7 said cavity ~~The apparatus of claim 24~~, wherein, said
8 cavity includes a first wall and a second wall opposing the
9 first wall, wherein the means for coupling is provided on
10 the first wall of the cavity, and wherein an exit opening
11 is defined in the second wall of the cavity at a location
12 opposed to the location of the means for coupling.

1 Claim 29 (original): The apparatus of claim 24, wherein
2 said cavity has a narrow section, a wide section, and a
3 tapered section arranged between the narrow and wide
4 sections.

1 Claim 30 (currently amended): An apparatus for supporting
2 generation of at least one hybrid arc/microwave plasma
3 discharge, the apparatus comprising:

4 a) a cavity supporting at least one of a TE mode and
5 a TM mode at a microwave frequency; and

6 b) means for coupling at least one torch module to
7 said cavity,

8 wherein said cavity has a narrow section, a wide
9 section, and a tapered section arranged between the narrow
10 and wide sections, and ~~The apparatus of claim 29~~ wherein
11 both the narrow section and the wide section have
12 rectangular cross sections.

1 Claim 31 (original): The apparatus of claim 30, wherein
2 the cavity is dimensioned to support a TE_{10n} mode at the
3 microwave source frequency, wherein n is an integer that is
4 at least 3.

1 Claim 32 (original): The apparatus of claim 28, wherein
2 said cavity includes endwalls substantially orthogonal to
3 the first and second walls, wherein torch plasma forming
4 the hybrid arc/microwave plasma discharge exits the cavity
5 from the exit opening of the second wall.

1 Claim 33 (original): The apparatus of claim 32, wherein
2 said cavity has a narrow section, a wide section, and a
3 tapered section arranged between the narrow and wide
4 sections,
5 wherein said cavity includes a narrow section defined
6 by the additional walls, the narrow section having a height
7 of about 5 mm, a first of the additional walls having a
8 first opening defined therein at which the torch module is
9 fixed, a second of the additional walls having a second
10 opening defined therein,
11 wherein the second opening permits the hybrid
12 arc/microwave plasma discharge to exit, and
13 wherein the first and second openings are located at
14 one of the electric field maximum locations of the TE_{10n}
15 mode, and the tapered section including two end locations,

16 the end locations of the taper section located at electric
17 field minimum locations of said TE_{10n} mode.

1 Claim 34 (currently amended): An apparatus for supporting
2 generation of at least one hybrid arc/microwave plasma
3 discharge, the apparatus comprising:

4 a) a cavity supporting at least one of a TE mode and
5 a TM mode at a microwave frequency; and

6 b) means for coupling at least one torch module to
7 said cavity,

8 wherein said cavity has a narrow section, a wide
9 section, and a tapered section arranged between the narrow
10 and wide sections, and wherein ~~The apparatus of claim 29,~~

11 the narrow section has a length of about $m\lambda_z/2$, where λ_z is
12 the wavelength of said TE_{10n} mode in the axial direction of
13 the cavity, and m is an integer determined by the number of
14 torches to be hosted in said cavity.

1 Claim 35 (new): The apparatus of claim 1, wherein in the
2 presence of microwave energy, the apparatus generates a
3 plasma torch which exits the cavity, said generated plasma
4 torch having a second energy level, said second energy
5 level being greater than said first energy level.

1 Claim 36 (new): The apparatus of claim 1, wherein said
2 apparatus is operable without cooling fluid.

1 Claim 37 (new): The apparatus of claim 1, wherein the
2 apparatus is operable without a vacuum chamber.

1 Claim 38 (new): The apparatus of claim 1, wherein said arc
2 torch module is powered by an electrical non-microwave
3 source and wherein said arc torch module generates an
4 electrical arc resulting in generated seed plasma used to
5 seed a microwave discharge to produce a high density plasma
6 torch.

1 Claim 39 (new): The apparatus of claim 1, wherein the
2 cavity is open to atmospheric conditions.

1 Claim 40 (new): The apparatus of claim 1, wherein a hybrid
2 arc microwave plasma discharge is generated independent of
3 whether or not a pressurized gas flow is present.

1 Claim 41 (new): The apparatus of claim 1, wherein a hybrid
2 arc microwave plasma discharge is generated independent of
3 whether or not the combination of the microwave source
4 output power level and Q of the cavity supports the
5 generation of plasma from microwave energy without the
6 introduction of seed plasma.

1 Claim 42 (new): The apparatus of claim 1, wherein a hybrid
2 arc microwave plasma discharge is generated independent of
3 whether or not the microwave source operates at an output
4 energy level sufficient to reach a breakdown threshold and
5 produce plasma without the introduction of seed plasma.

1 Claim 43 (new): The apparatus of claim 18,
2 wherein said cavity is a low Q cavity with a value
3 less than 30, and
4 wherein said microwave source is operated at an output
5 energy level resulting in microwave energy levels within

6 said cavity being below breakdown threshold in the absence
7 of seed plasma.

1 Claim 44 (new): The apparatus of claim 1 further
2 comprising:

3 d) synchronization circuitry to keep arc discharge in
4 synchronization with microwave discharge in each
5 cycle.

1 Claim 45 (new): The apparatus of claim 26, wherein an
2 implemented combination of the microwave source output
3 power level and cavity Q is insufficient to generate plasma
4 from the microwave energy without an introduction of seed
5 plasma.

1 Claim 46 (new): The apparatus of claim 1, wherein the
2 apparatus is portable.

1 Claim 47 (new): The apparatus of claim 1, wherein said
2 microwave source and said arc torch module are directly
3 coupled to said cavity.

1 Claim 48 (new): The apparatus of claim 1, wherein plasma
2 is produced in an open environment.

1 Claim 49 (new): The apparatus of claim 1, wherein the
2 plasma is directed in the absence of a confining tube.

1 Claim 50 (new): The apparatus of claim 1, wherein said
2 apparatus is operable in the absence of a stub tuner or
3 mode conversion device to achieve microwave coupling to a

- 4 degree sufficient to produce microwave based plasma
- 5 discharge.